Accelerated Insertion of Materials - Composites

Presented at SAMPE
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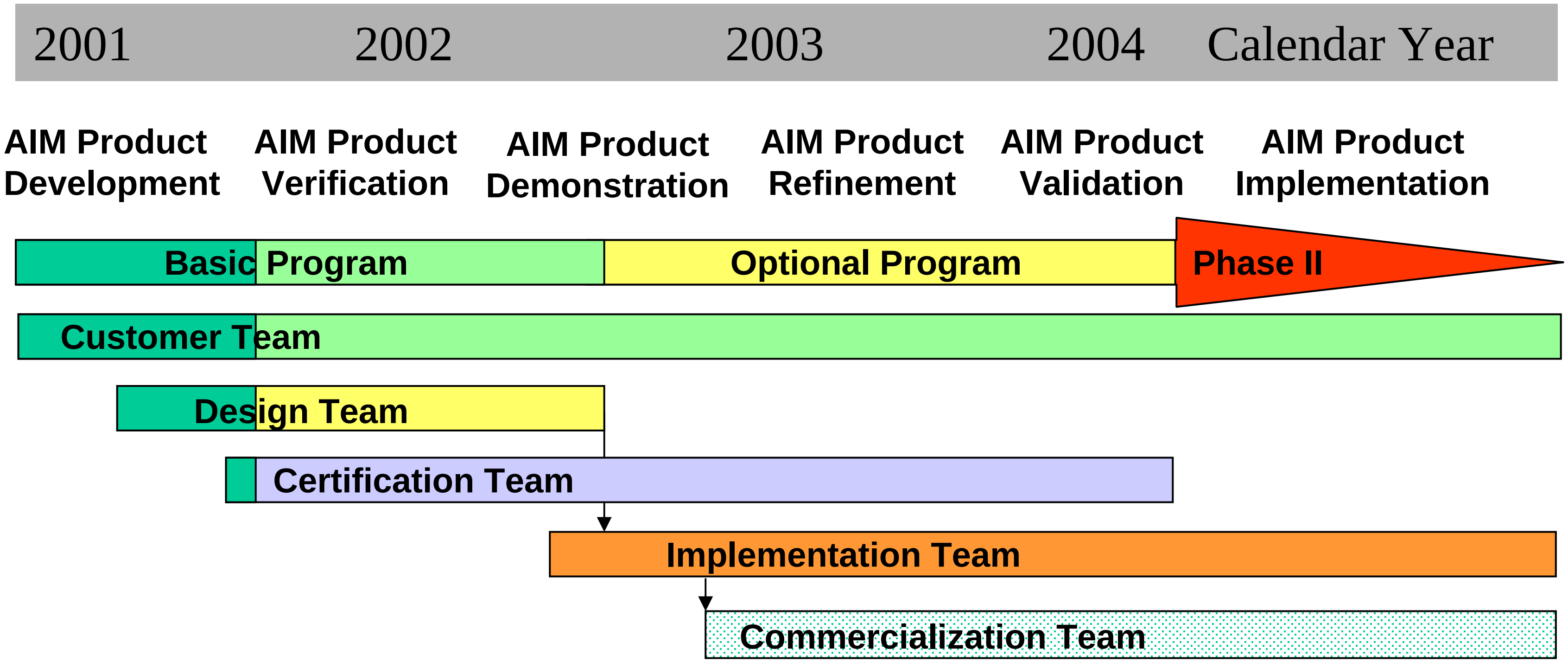
Jointly accomplished by BOEING and the U.S Government under the guidance of NAST

This program was developed under the guidance of Dr. Steve Wax and Dr. Leo Christodoulou of DARPA. It is under the technical direction of Dr. Ray Meilunas of NAVAIR.

Technology Transition Plan

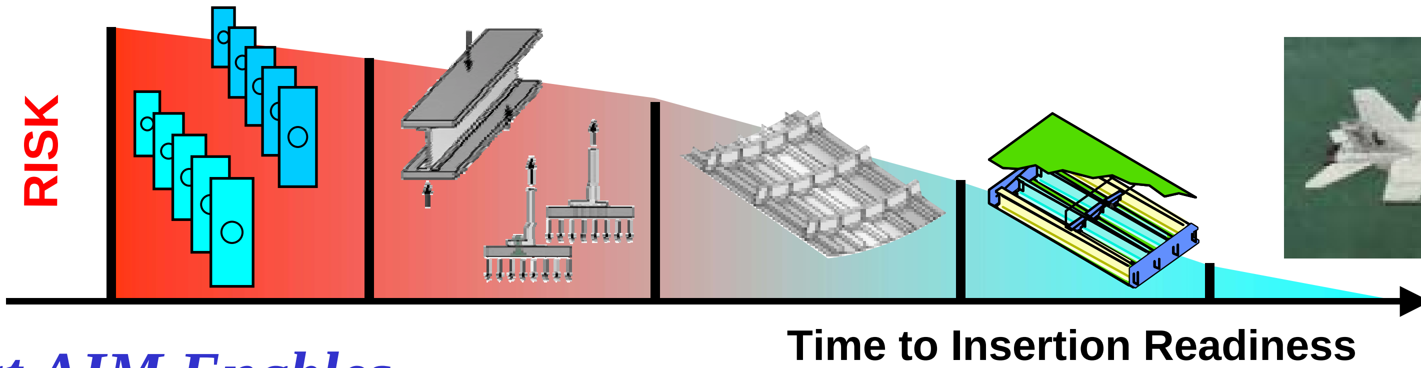


The Objective of the AIM-C Program is to Provide Concepts, an Approach, and Tools That Can Accelerate the Insertion of Composite Materials Into DoD Products

Accelerated Insertion of Materials

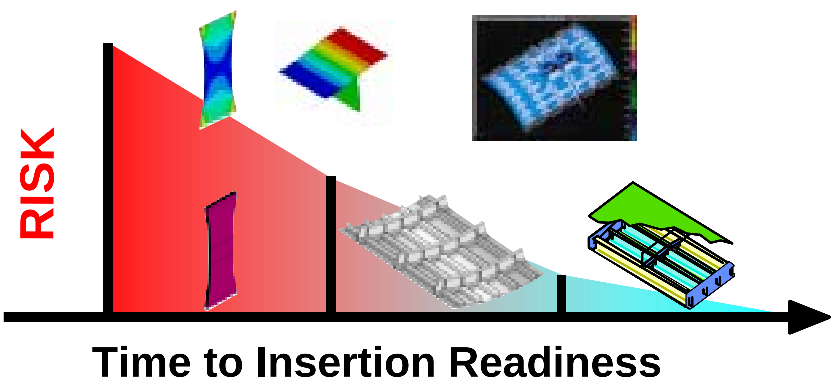
Traditional Building Block Approach Improves Confidence by Extensive Testing Supported by Analysis:

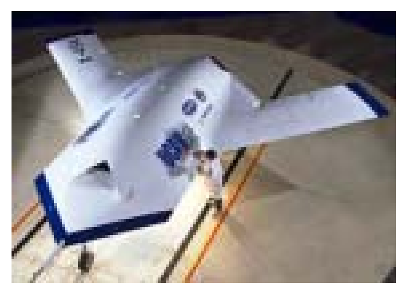
Too Often Misses Material Insertion Windows



What AIM Enables

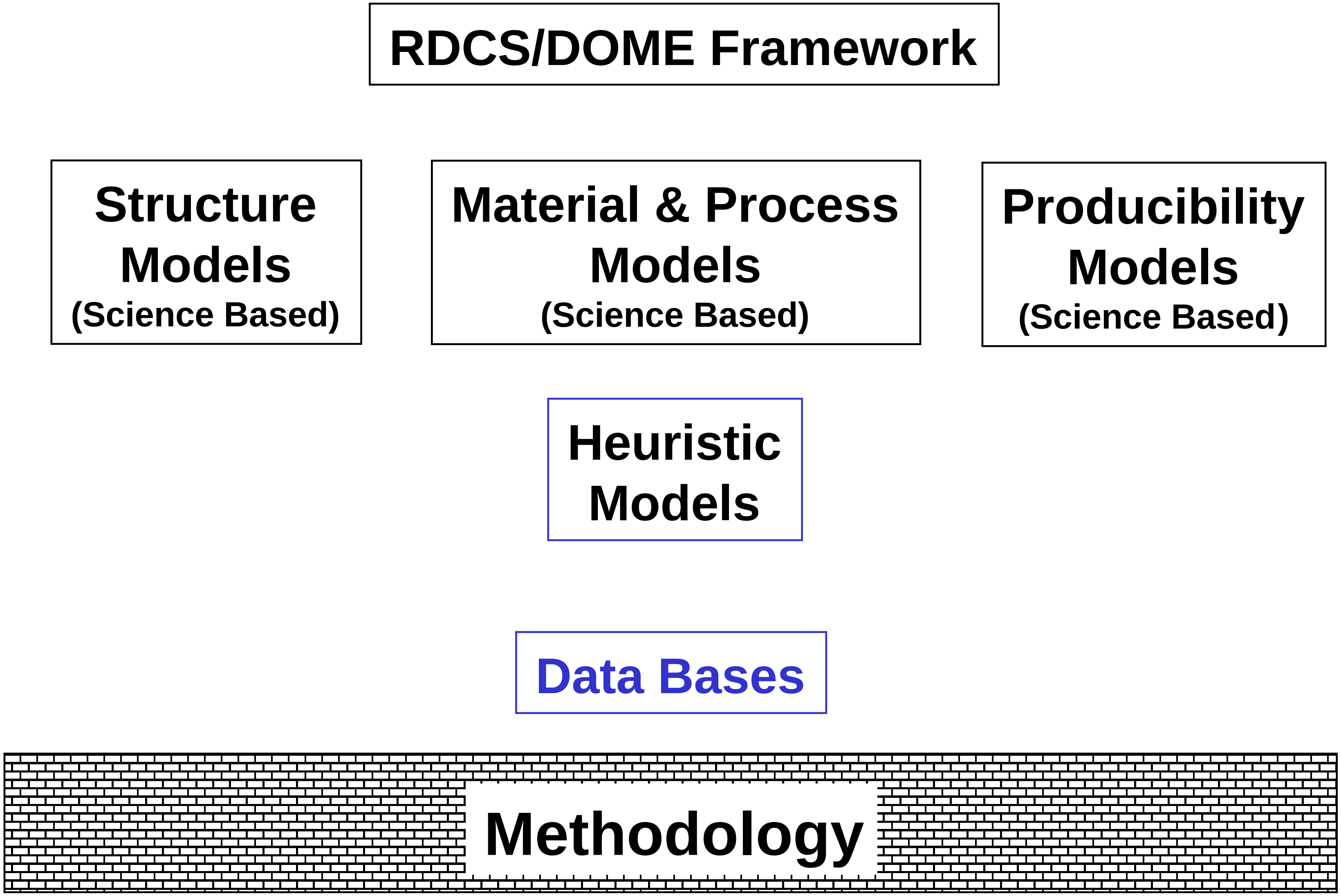
AIM Methodology Improves Confidence More Rapidly & Effectively by Analysis Supported By Test / Demonstration -
***Focusing* on the Designer Knowledge Base Needs**





Benefits
50% Time Reduction
33% Cost Reduction

Methodology is the Foundation of the AIM-C Comprehensive Analysis Tool

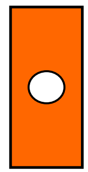


“Building Block” Test Program

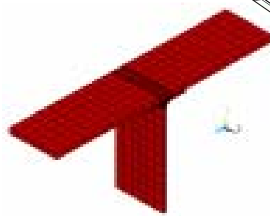
Material/Process and Design Development

Material Selection
- Metals
- Composites

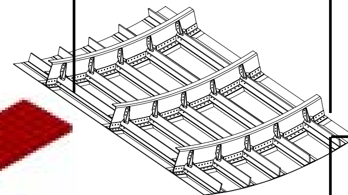
Manufacturing Process
- Process Development
- NDT Standards



Material Properties
- Repair
- Physical/ Chemical/ Processing
- Environmental Effects
- Mechanical Properties
- Statistical Knockdown
- Fatigue Scatter
- Effects of Defects



Elements/ Subcomponents
- Design Details
- Damage Tolerance
- Repair
- Validation of Analysis Methodology
- Fatigue
- Static
- Acoustic

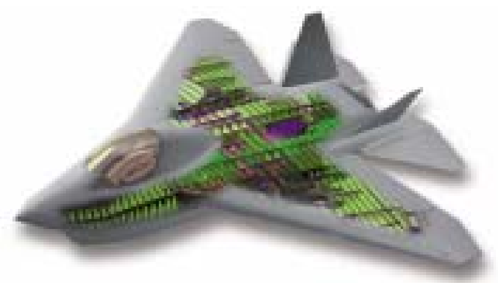


Components
- Configuration Details
- Damage Tolerance
- Static
- Fatigue
- Repair
- Validation of Analysis Methodology

Reproduction Verification

Full Scale Laboratory Certification Tests
- Static
- Fatigue
- Drop
- Dynamics

EMD Aircraft
- Flight Test
- Ground Test



DESIGN TEAM'S NEEDS
Requirements are Multi-Disciplined

Structural

- Strength and Stiffness
- Weight
- Service Environment
  - Temperature
  - Moisture
  - Acoustic
  - Chemical
- Fatigue and Corrosion Resistant
- Loads & Allowables
- Certification

Manufacturing

- Recurring Cost, Cycle Time, and Quality
- Use Common Mfg. Equipment and Tooling
- Process Control
- Inspectable
- Machinable
- Automatable
- Impact on Assembly

Supportability

- O&S Cost and Readiness
- Damage Tolerance
- Inspectable on Aircraft
- Repairable
- Maintainable
  - Accessibility
  - Depaint/Repaint
  - Reseal
  - Corrosion Removal
- Logistical Impact

Material & Processes

- Development Cost
- Feasible Processing Temperature and Pressure
- Process Limitations
- Safety/Environmental Impact
- Useful Product Forms
- Raw Material Cost
- Availability
- Consistency

Miscellaneous

- Observables
- EMI/Lightning Strike
- Supplier Base
- Applications History
- Certification Status
  - USN
  - USAF
  - ARMY
  - FAA

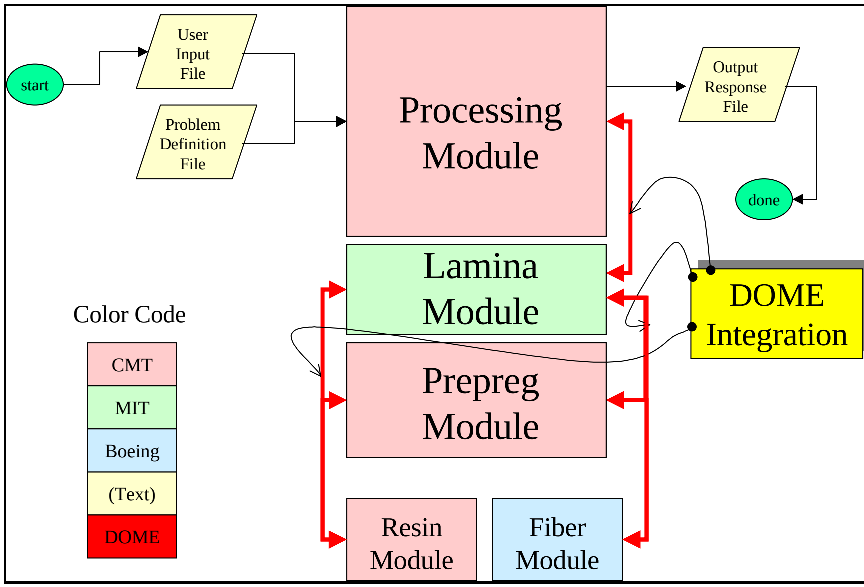
Risk in Each Area is Dependent Upon Application's Criticality and Material's Likelihood of Failure

AIM-C Methodology Addresses All Elements of the Maturation Process Concurrently

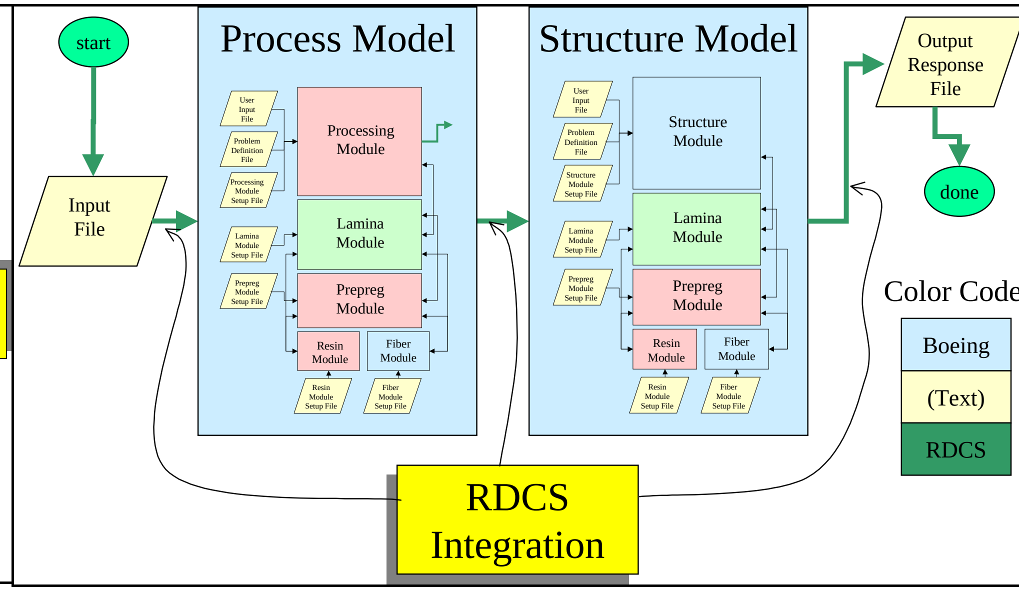
TRL	1	2	3	4	5	6	7	8	9	10
Application Maturity	Concept Exploration	Concept Definition	Proof of Concept	Preliminary Design	Design Maturation	Component Testing	Ground Test	Flight Test	Production	Recycle or Dispose
Application Risk	Very High	High	High - Med	Med - High	Medium	Med - Low	Low	Low - Very Low	Very Low	Negligible - Recycle or Disposal
Certification		Certification Plan Documented	Certification Plan Approved	Preliminary Design Allowables	Design Allowables / Subcomponents	Full Scale Component Testing	Full Scale Airframe Tests	Flight Test	Production Approval	Disposal Plan Approval
Assembly	Assembly Concept	Assembly Plan Definition	Assembly Definition	Assembly Details Tested	Subcomponents Assembled	Components Assembled	Airframe Assembled	Flight Vehicles Assembled	Production	Disassembly for Disposal
Design	Concept Exploration	Concept Definition	Design Closure	Preliminary Design	Design Maturation	Ground Test Plan	Flight Test Plan	Production Plan	Production Support	Disposal Support
Supportability		Repair [illegible]	Repair Processes Documented	Fabrication Process Repairs Identified	Fabrication Repair Process Trials Subcompone[illegible]	Repair of Component Test Articles	Production Repairs Identified	Flight Qualified Repairs Documented	Repair / Replace Decisions	Support for Recycle or Disposal Decisions
Cost/Benefit Maturity	Cost Benefit Projected									
Structures Maturity	Potential Benefits Predicted									
Fabrication Maturity	Target Applications Identified									
Quality										
Materials Maturity	Key Target Properties Defined from Chemistries									
Intellectual Rights	Concept Documented									

	Development	Feasibility	Practicality	Application
Customer				
Design				
Business				
Vendor				

Architecture of the AIM-C Comprehensive Analysis Tool (CAT)



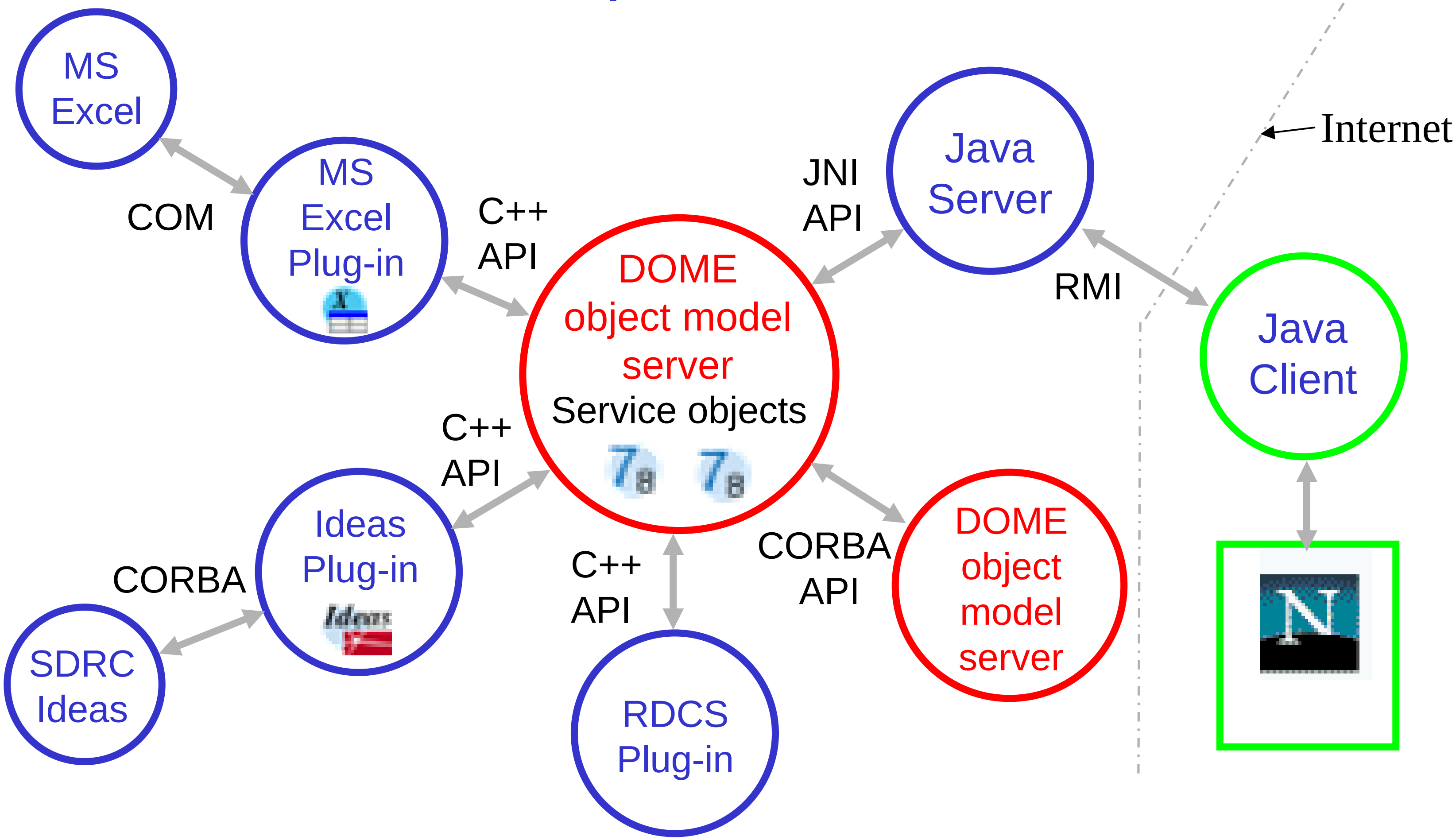
Distributed Object Oriented Modeling Environment (DOME) links



Robust Design Computing System (RDCS) links

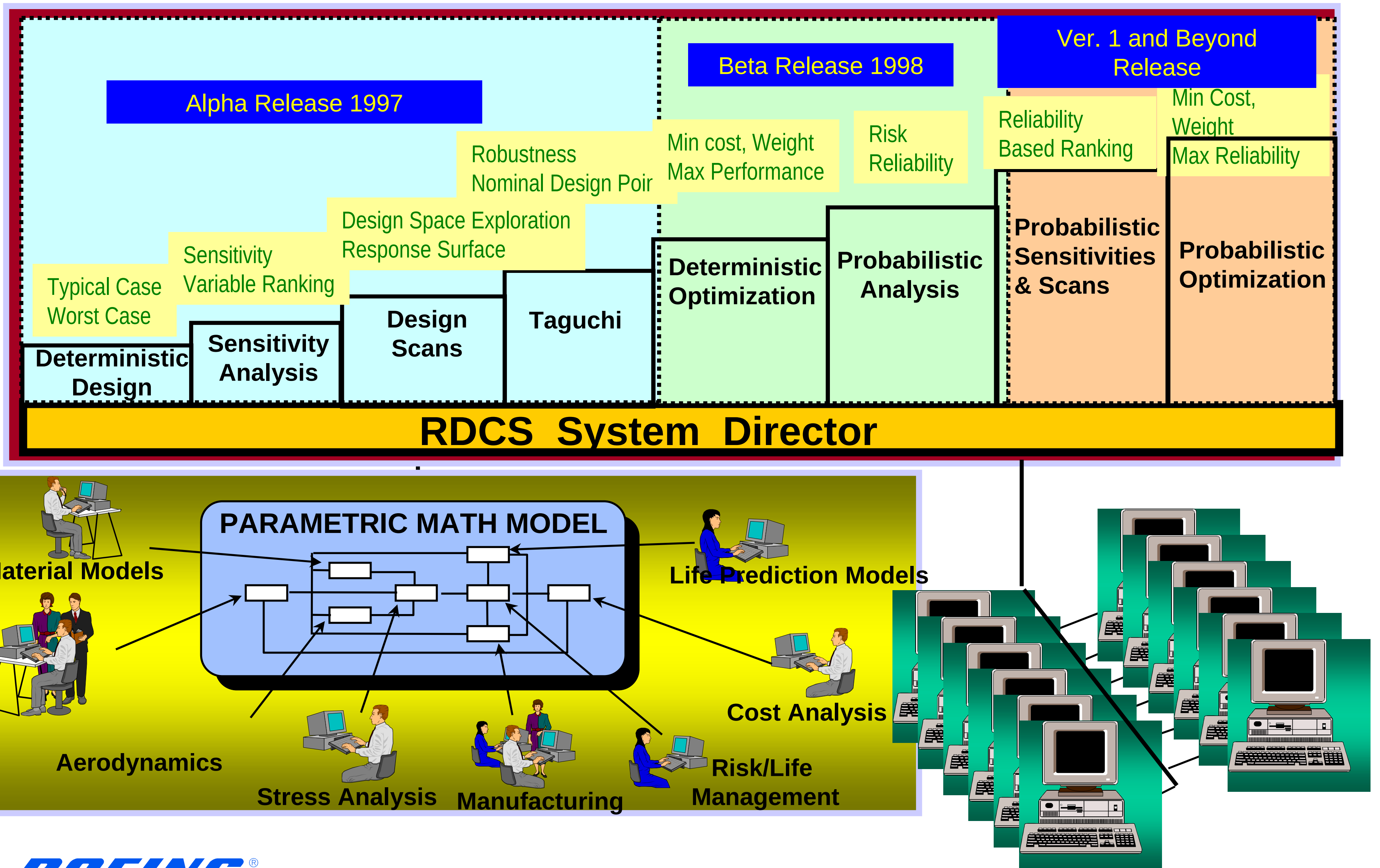
Distributed Object Oriented Modeling Environment

DOME Architecture: Conceptual Overview



Addresses heterogeneity, interoperability, accessibility, complexity, scalability, flexibility, & proprietary knowledge

RDCS Tool
An Instance of Modern Design Framework



DARPA Cooperative Agreement 7/96 - 12/99 ($6 M)

RDCS and DOME Use In AIM Complement Each Other - Summary

Distributed Object Oriented Modeling Environment (DOME)

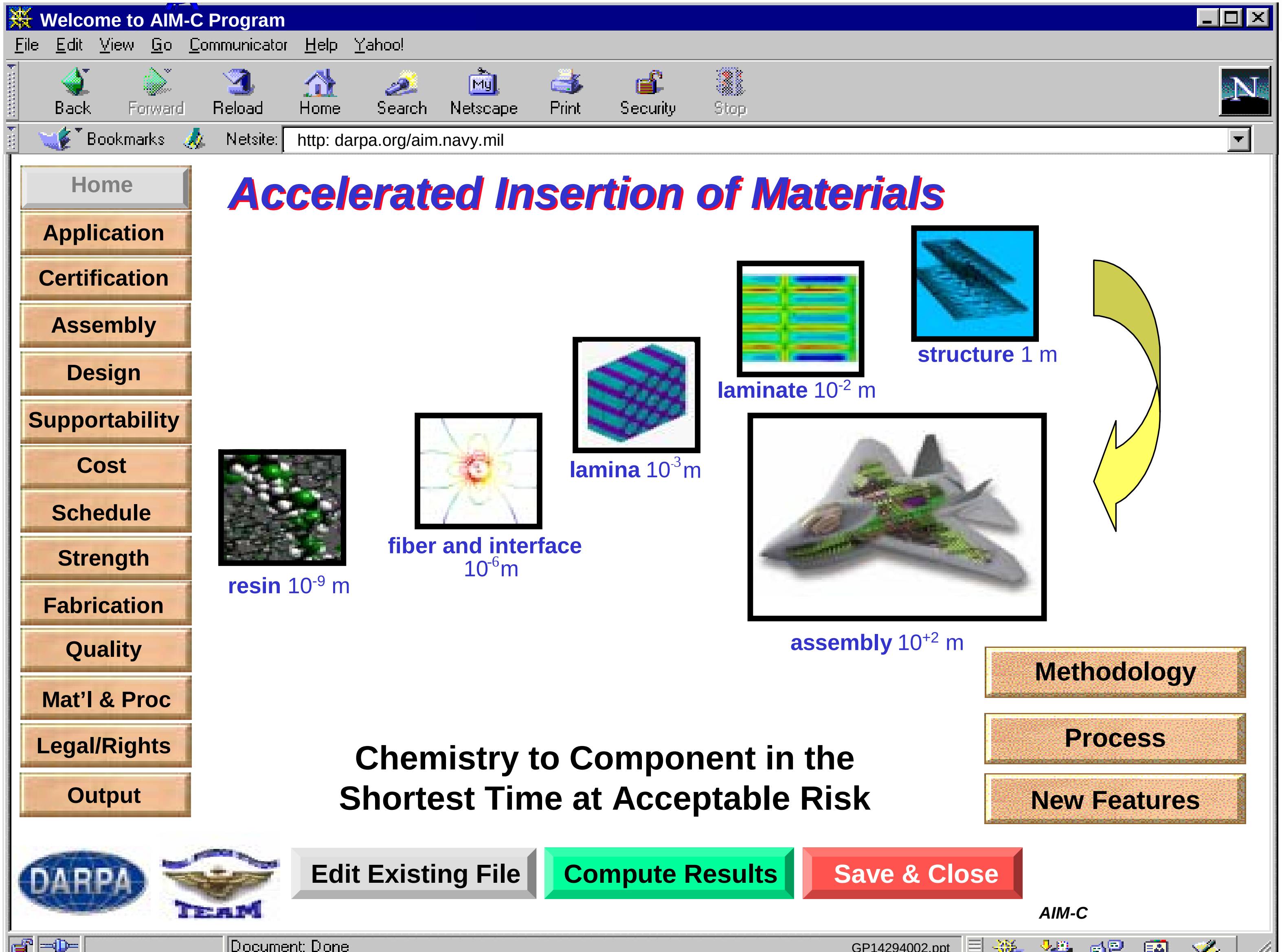
- Emphasizes Distributed Services
- Emphasizes transaction based code communications
- Enables geographically distributed code executions in a services paradigm
- Heterogeneous PC and Unix Workstations

Robust Design Computing System (RDCS)

- Emphasizes Design Process
- Meets the need for File Based communication between Compute Intensive Codes- Load Balancing
- Emphasizes parallel distributed computing within the enterprise network (e.g. 100's of Unix work stations used in parallel to solve the problem)
- Heterogeneous Unix Workstations

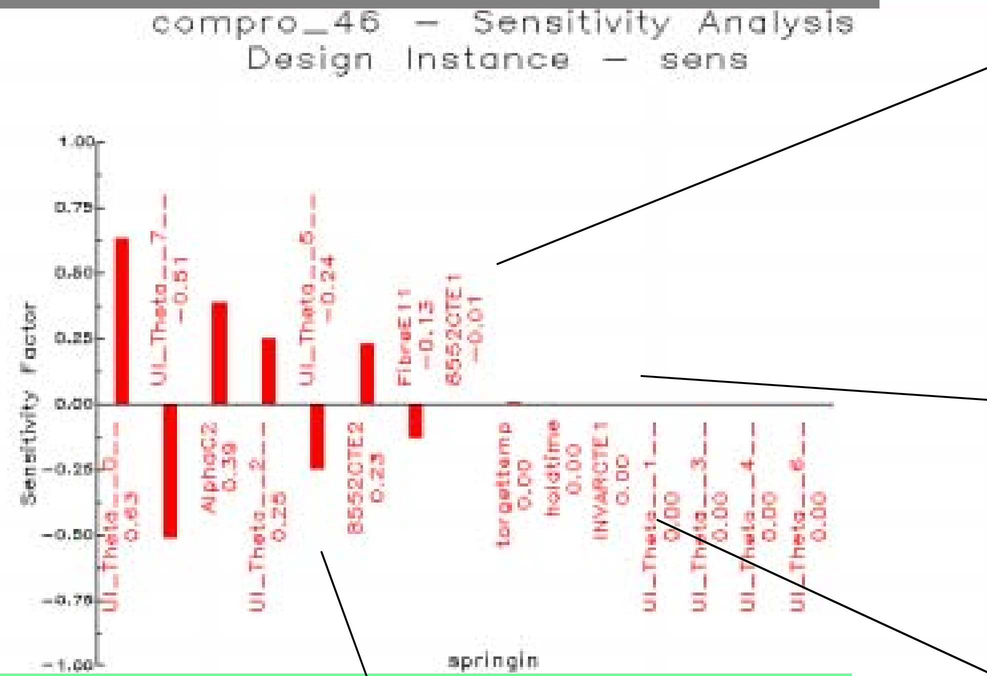
RDCS and DOME capabilities provide the AIM team state of the art design framework tools for integrating and analyzing material and other multi-disciplinary models.

Conceptual Vision of the AIM-C CAT User Interface



Example of an Output Screen for the AIM-C CAT

Drivers of Cost, Schedule, Technical Outcomes



Related Tests

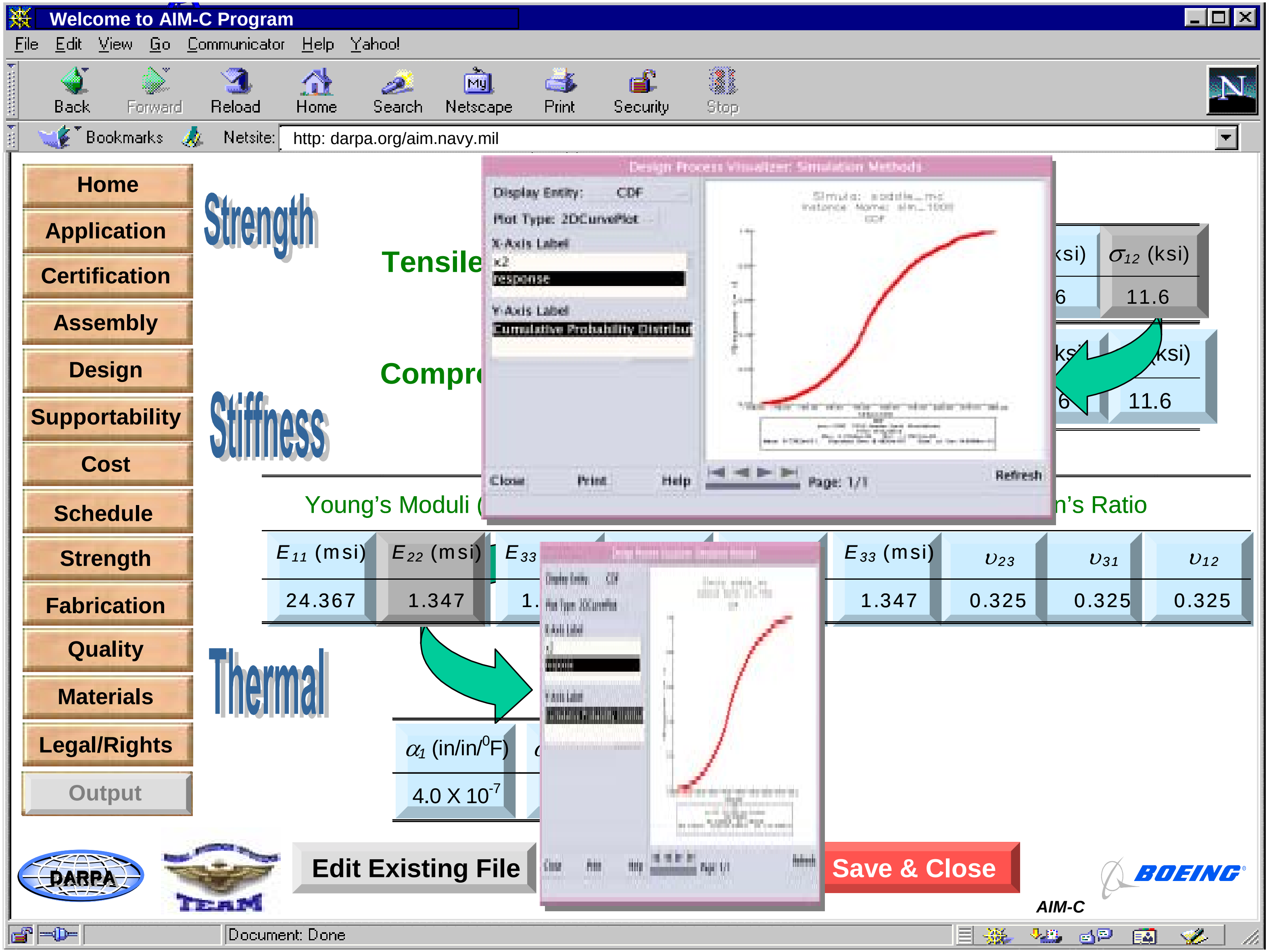
Recommended Analysis Methods

Recommended Demonstration Features

Further considerations

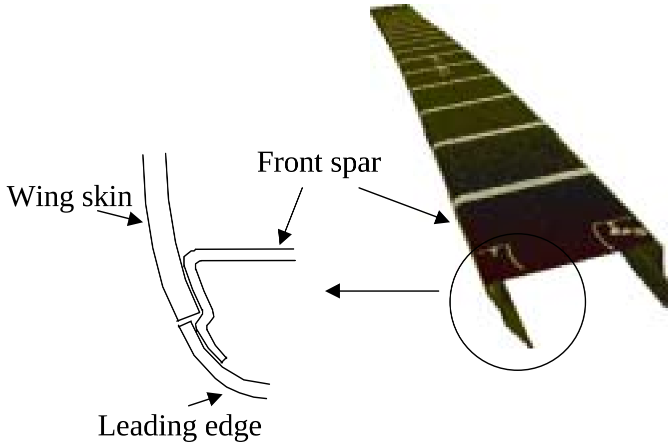
- More interrogations
- Links to related lessons learned
- Links to more information

Example of an Output Screen for the AIM-C CAT

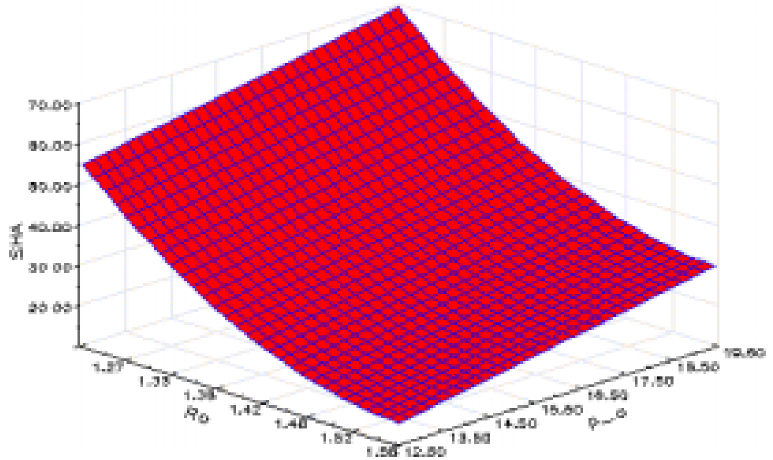


AIM-C CAT Benefits: COMPRO Integration with Robust Design Computational System (RDCS)

767-400 Raked Wingtip Front Spar DOE Sensitivity Analysis



RDCS Sensitivity Analysis Plus Design Scan



Conventional Approach

- 32-Runs for Simple DOE
- 4-Months Calendar Time to Set-Up and Solve
- Computer (time) intense
- 216-Hrs Actual Labor to Complete
- Labor-Intense Data Reduction

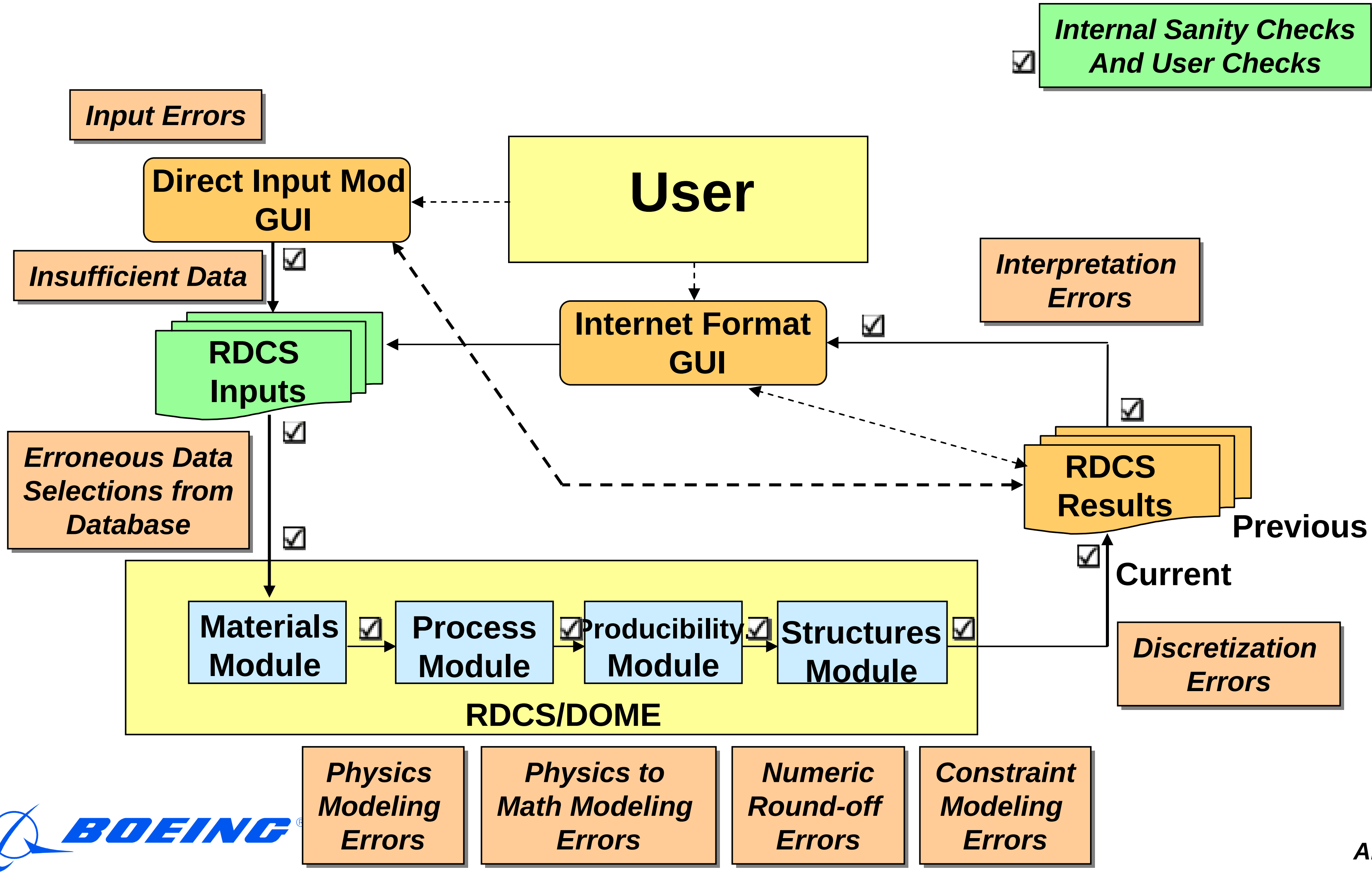
Integrated with RDCS

- 127-runs for Sensitivity Analysis and Design Scan
- 1-2 Weeks Calendar Time to Set-Up and Solve
- User Isolated from Intense Interaction with Multiple Codes
- 28-Hrs. Actual Labor to Complete
- Automated Data Reduction and Graphics

Modeling of the Fiber – Uncertainty Management

<table>
<tr>
<th></th>
<th>Inherent variations associated with physical system or the environment (Aleatory uncertainty)
Also known as variability, stochastic uncertainty
E.G. manufacturing variations, loading environments</th>
<th>Uncertainty due to lack of knowledge (Epistemic uncertainty)
inadequate physics models information from expert opinions.</th>
<th>Known Errors (acknowledged)
e.g. round-off errors from machine arithmetic, mesh size errors, convergence errors, error propagation algorithm</th>
<th>Mistakes (unacknowledged errors)
human errors e.g error in input/output, blunder in manufacturing</th>
</tr>
<tr>
<td>Coefficient of thermal expansion, $\alpha 1$, $\alpha 2$</td>
<td rowspan="4">Batch to batch variation in material, arising from variations in PAN precursor, and carbonization process</td>
<td rowspan="4">Models almost always assume no temperature or moisture effect.</td>
<td rowspan="4">Lack of direct measurement techniques; property is measured on a lamina/laminate basis.</td>
<td rowspan="4">Back-calculation values based on micromechanics. Complex experimental methods.</td>
</tr>
<tr>
<td>Modulus (E11, E22)</td>
</tr>
<tr>
<td>Strength (to failure)</td>
</tr>
<tr>
<td>Strain (to failure – linked to strength)</td>
</tr>
</table>

Error Sources and Mitigation in The AIM-C Product



The Development Path of the AIM-C CAT

Basic Product	**Architecture Backbone in Place** **Limited Heuristic Link to Methodology** **Modules Very Limited Utility** **No AIM User Interface / Use existing DOME and RDCS interfaces**
Optional Product	**Architecture with Moderate Robustness** **Firm Heuristic Link to Methodology** **Modules with Validated Functionality** **Internet User Interface for Input**
Phase II Product	**Architecture Robust** **Firm Heuristic Link to Methodology** **Modules with Complete Functionality** **Internet User Interface for Real Time Input / Output Manipulation Capability**

Industry Benefits from AIM

- Cost, schedule, performance with confidence factor
- Focus based on needs
- Knowledge management – orchestrated models, simulations, experiments to maximize useful information
- Built on building block methodology while facilitating discipline integration
- Internet access
- Path from criteria based to probabilistic based approaches
- Platform support for changes – bill of materials, pedigree, re-certification
- Design process application
- The best of emergent modeling and explicit modeling
- Applications to other problem sets

Improve productivity, facilitate radically new approaches to material insertion